What Controls the Shallow Fault Damage Zone & Fluid Flow?

Insights from New High-Resolution Seismic Imaging

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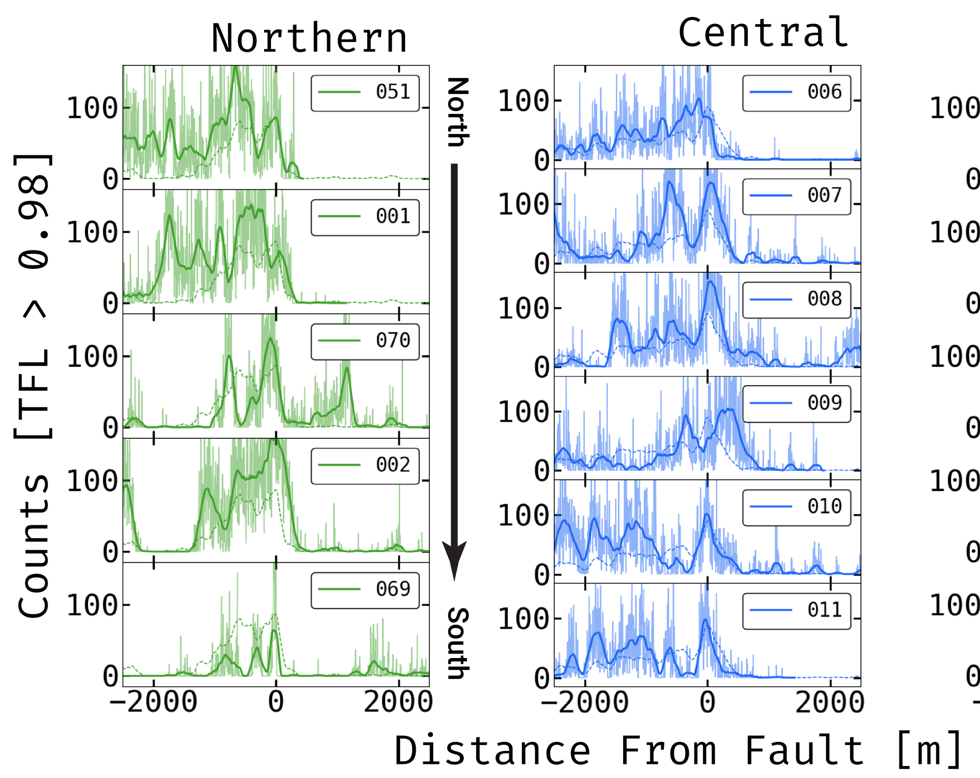
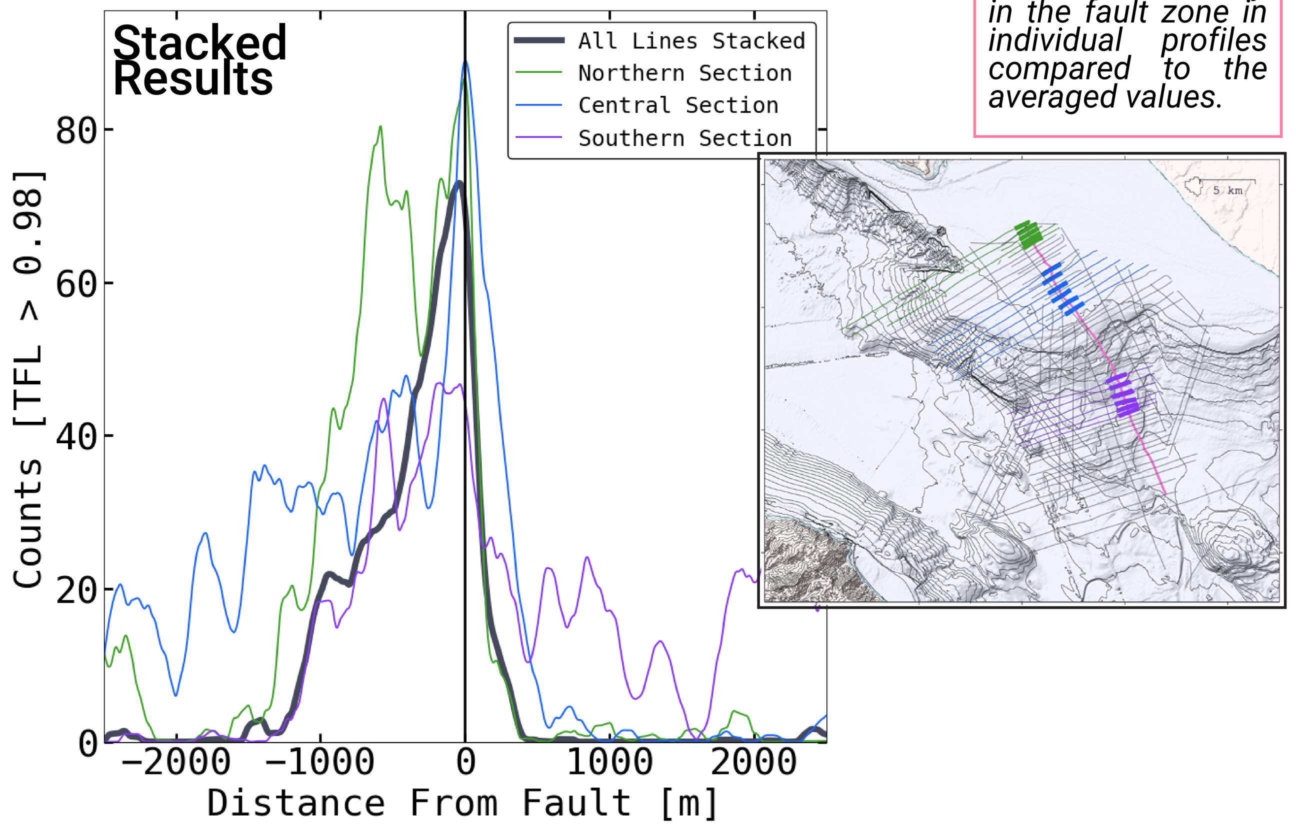
Complex fault damage patterns localize around active fault strand



Note the variability in the fault zone in individual profiles compared to the averaged values.

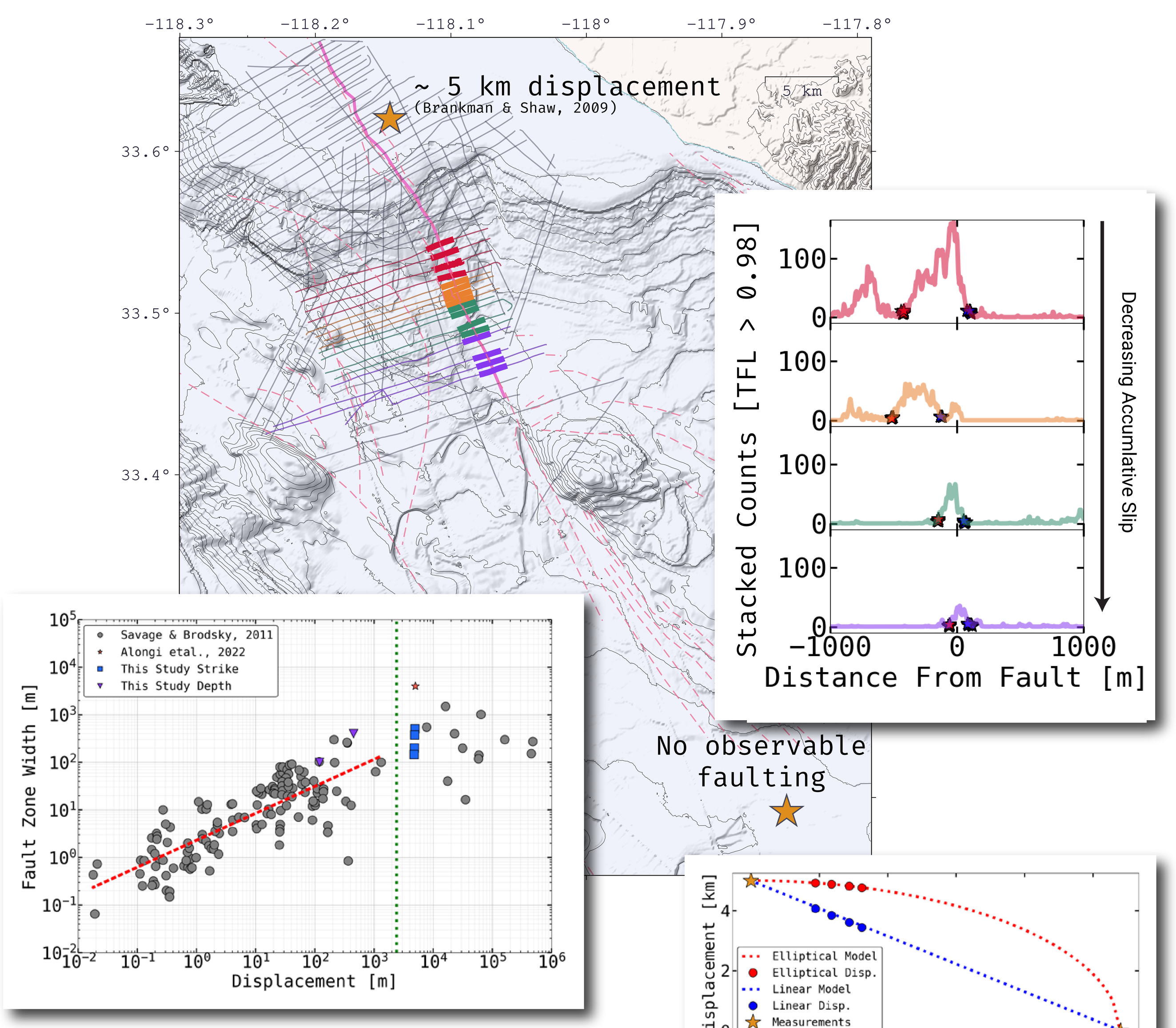


Distribution of high probability thinned fault likelihood (TFL) detections calculated from the multichannel seismic data over the **depth range from the seafloor to 400 ms two-way travel time below the seafloor**.

Top- Individual line curves for different fault sections. The light-weight lines represent the number of samples in the trace (3 m sampling) that exceeded 0.98 TFL. The heavy-colored lines are smoothed data.

Bottom- The median stack of each section where the heavy-weighted dark line represents the median stack of all fault perpendicular lines.

How does fault displacement impact the damage zone?



$$u = 2\Delta\sigma\left(\frac{(1-\nu)}{G}\right)\left(a^2 - x^2\right)^{1/2}$$

u - displacement
Δσ - stress drop
a - fault half length
x - distance from center
G - shear modulus
ν - poisson ratio

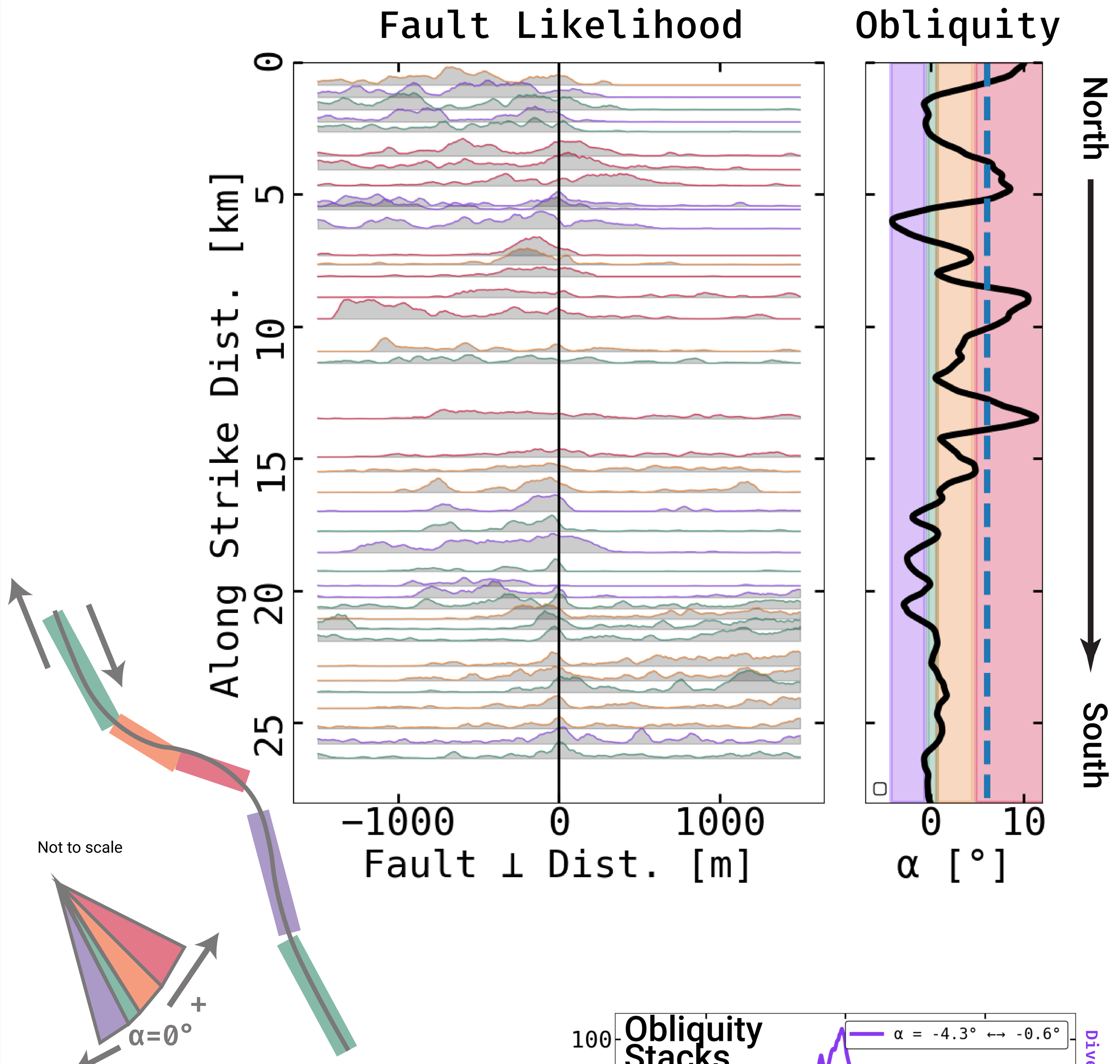
Comparing the variation in the damage zone width to the decrease in cumulative fault displacement to the south-east.

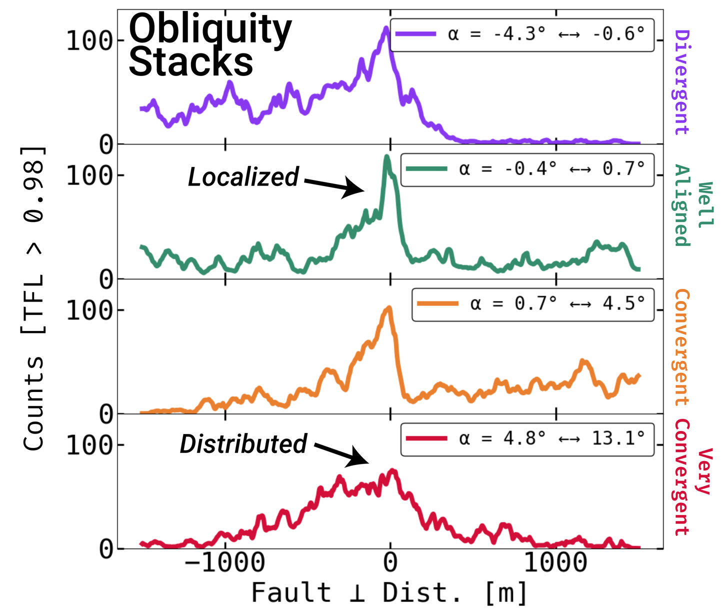
We utilize measured displacement of 5 km on the shelf (Brankman and Shaw, 2009) and establish a point 50 km away that exhibits no faulting as zero displacement. We calculate an idealized accumulated displacement with the above equation (Pollard and Segall, 1987).

The width of the damage zone is determined by identifying the points where 5% of the peak values are located, marked as red & blue stars (upper right).

Plotting the results of the damage width and displacement presented here (blue squares) along with compilation study (Savage & Brodksy, 2011) shows relatively good agreement (lower right). However, the trend of the data presented in this study suggests the influence of another factor on the observed damage trends.

Obliquity influences damage zone width





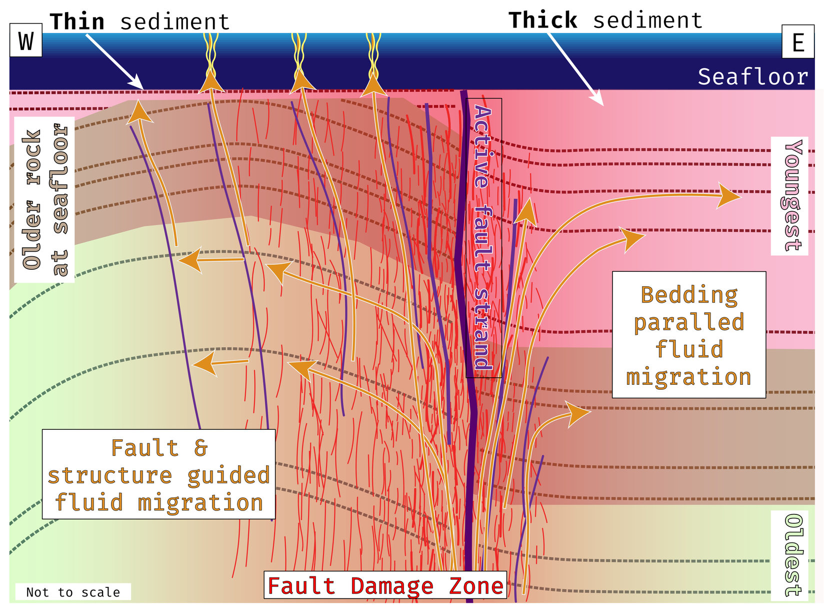
Here we investigate the impact of oblique convergence on fault damage.

We observe that the fault zone is highly localized in the southern portion of the survey. The simplicity of the fault and the absence of near-fault deformation suggests that the fault is aligned with the local stress field. We use this azimuth or obliquity as a reference, and measure deviation in fault strike (α).

To analyze this, we group the thinned fault likelihood (TFL) curves into obliquity bins of equal size (with consistent colors throughout). Subsequently, we stack the curves in each obliquity bin.

Note the relative localization of damage in the well aligned portions of the fault and the distributed damage in the highly convergent regions.

Fluid flow is influenced by fault damage and sediment thickness



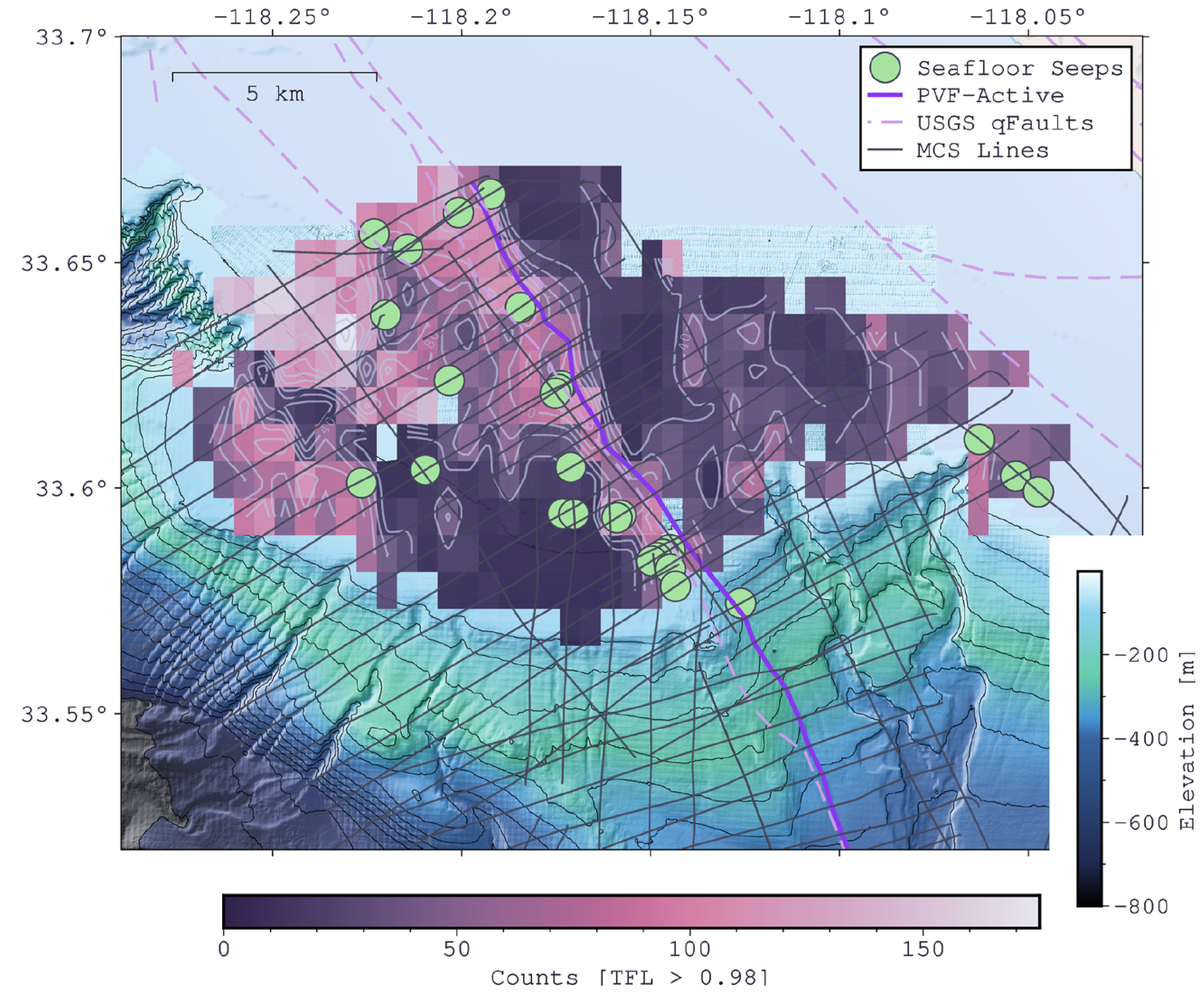
Schematic cross-section cartoon representing the fluid system surrounding the Palos Verdes Fault.

Fluids generated at depth **migrate** toward the seafloor through the **high permeability fault damage zone**, represented by red subvertical lines.

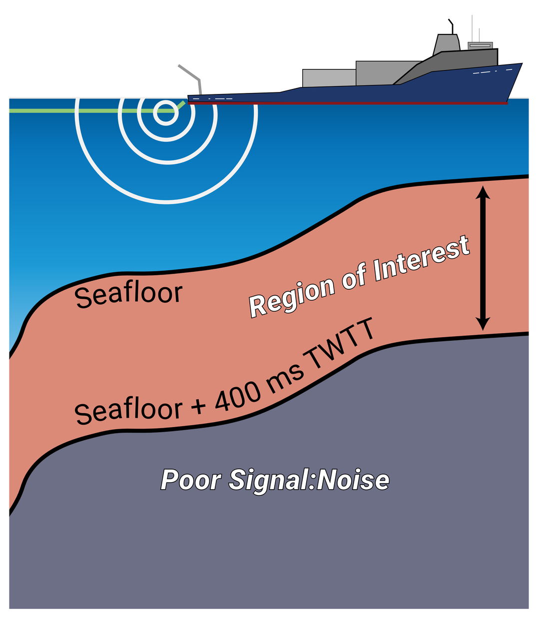
The fault damage, combined with the tectonic history of the Palos Verdes Fault region, influences the spatial distribution of fluids released at the seafloor.

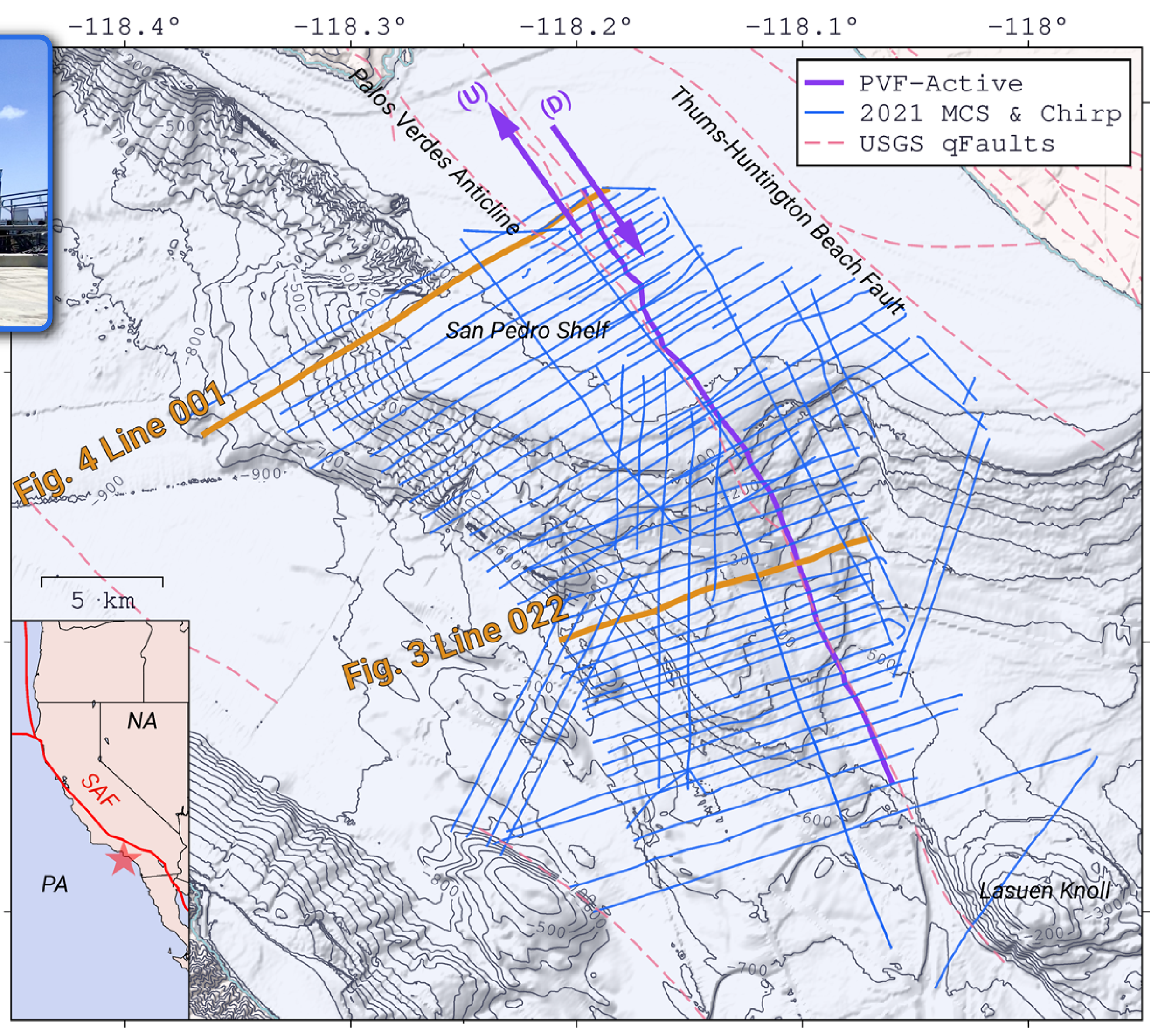
Long-term uplift **west** of the fault brings **older, more damaged rock closer to the seafloor**, preventing the accumulation of Quaternary sediments; this facilitates the **release of fluids**.

Conversely, to the **east** of the fault where the **damage is low and a thick sediment cap exists**, fluids tend to be **trapped** within formation beds.



Data & Methods





(a) **Sparker MCS - Processing**

1. Import raw data
2. Calculate source - receiver geometry
3. QC stack data
   i) Pick water bottoms
   ii) Semblance velocity analysis
4. Surface Related Multiple Elimination
5. Pre-stack statistical deconvolution
6. Normal moveout w/ velocity table
7. Trimstatics (flatten streamer)
8. Common midpoint stack
9. Post-stack migration
10. Top and bottom mute
11. Structurally oriented denoise
12. Export segy

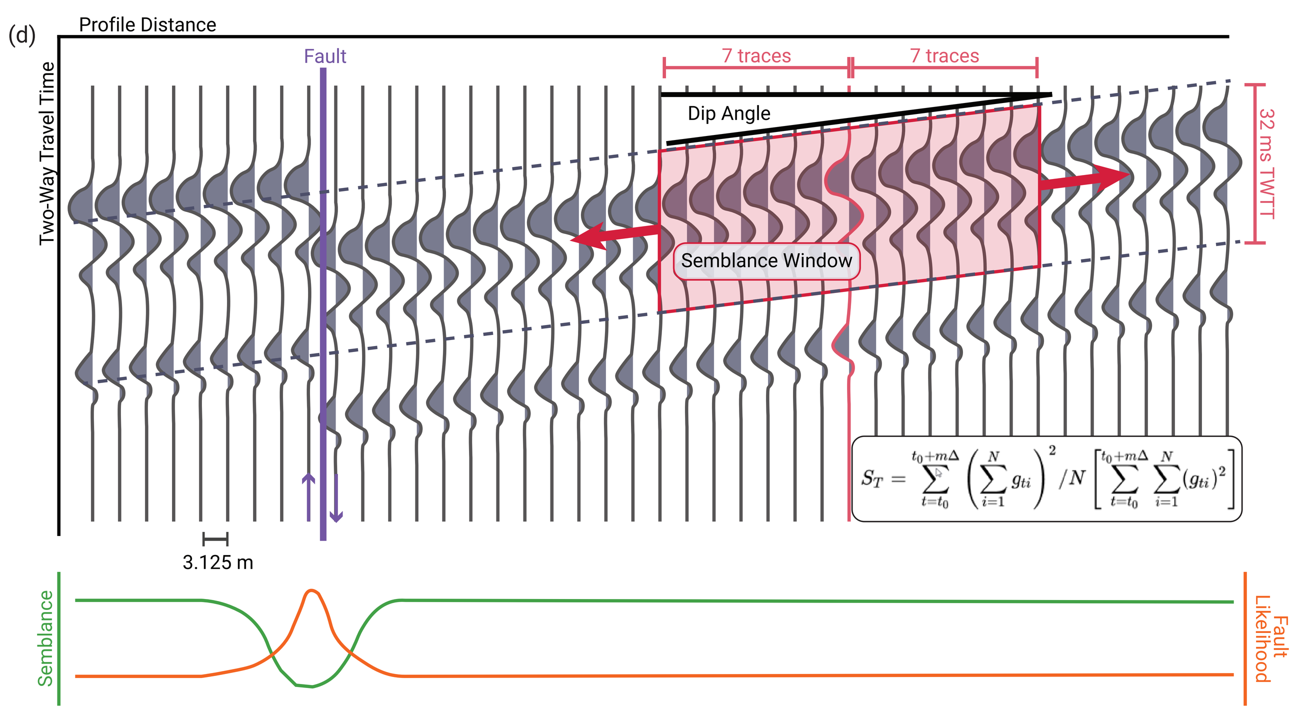
(b) **Sparker MCS - Fault Detection**

a. Dip-steering - Filter size 7 x 128
b. Fault Enchancement Filter
c. Thinned Fault Likelihood

(c) **Observables**
Fault Locs
Seafloor Scarps
Seafloor Seeps
Fault Damage

Datasets
2021 USGS Chirp
2021 USGS MCS

(d)



Data Examples

Chirp sub-bottom profile example. The white bars indicate the length and depth; note the **extreme vertical exaggeration** of the profile to highlight the fault scarp and fluid seeps.

The Palos Verdes fault (red vertical line) clearly marked by a sharp boundary between horizontally continuous Quaternary sediments to the northeast and deformed Miocene lithologies to the southwest.

Along the shelf, all profiles crossing the fault exhibit a **notable scarp** at the fault location that helps determine **activity**.

Comparison of the processed **multichannel seismic (MCS)** profile and with the **thinned fault likelihood (TFL)** attribute results.

Palos Verdes Fault (shown in purple) identifiable by offset reflectors, folding, and near fault deformation features.

The **TFL attribute is truncated** to highlight high fault likelihoods (TFL > 0.98) this damage metric is used consistently used throughout the study, and represent high fault likelihood or dissimilarity in seismic data.